InLCA: Case Studies – Using LCA to Compare Alternatives

Life Cycle Considerations of the Flue Gas Desulphurization System at a Lignite-Fired Power Plant in Thailand

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Abstract

DOI: http://dx.doi.org/10.1065/lca2004.09.180.8

Goal, Scope and Background. The Flue Gas Desulphurization (FGD) system has been installed at the biggest lignite-fired power generation plant in Thailand to reduce the large amount of SO_2 emission. In order to understand the costs and benefits, both in ecological and economic terms, the lignite-fired plant was studied both before and after the installation of the FGD system. The focus of this study is to consider not only the Life Cycle Assessment (LCA) outcome but also the Life Cycle Costing (LCC) factors. The results can provide valuable information when selecting appropriate technologies to minimize the negative impact that lignite-fired power plants have on the environment.

Methods. The Life Cycle Assessment – Numerical Eco-load Total Standardization (LCA-NETS) system was used to evaluate the impact on the environment of both the lignite-fired plant and the FGD system. Life Cycle Costing (LCC) was used to provide a comparison between alternative before and after installation of FGD. LCC, a powerful analytical tool, examines the total cost, in net present value terms, of a FGD system over its entire service lifetime.

Results and Discussion. The results of the study are shown in the eco-load values over the entire life cycle of the lignite-fired plant. Comparative models of the power plant, before and after the installation of the FGD system, are evaluated using the LCA-NETS system. The results indicate that the installation of the FGD system can reduce the acidification problem associated with lignite-fired plants by approximately 97%. The LCC estimation shows the major costs of the FGD system: capital investment, operating and maintenance, and miscellaneous costs. The LCC provides the decision-making information when considering the cost of the FGD system in terms of protecting the environment.

Conclusion and Outlook. LCA is an important decision-making tool for environmental policies, especially with regard to the selection of pollution control equipment for lignite-fired plants. Green coal technologies and strategies to reduce the negative impact on the environment are essential to produce more environmentally-friendly power plants with a sustainable future.

Keywords: Externality analysis; flue gas desulphurization; life cycle assessment; life cycle costing; lignite-fired power generation plant; numerical eco-load total standardization; Thailand

Introduction

The mine-mouth coal-fired power generation plant at Mae Moh district, Lampang Province, the biggest thermal power generation plant in Thailand, uses lignite as a combustible fossil fuel. In the fiscal year 2001, Electricity Generating Authority of Thailand (EGAT) statistics for total electricity production in Thailand, classified by resource, were as follows: natural gas 33%, lignite 16%, hydropower 6%, fuel oil 2%, diesel oil 0.2%, and alternative renewable energy less than 0.2% [1,2]. These figures showed that the Mae Moh plant, producing 16% of the total, is the second largest producer in Thailand. In the same year, approximately 41% of electricity production was purchased from Independent Power Producers (IPP) and Small Power Producers (SPP), with almost 2% purchased from neighbouring countries. The sulphur content of lignite in the Mae Moh region is around 3%. SO_2 emission from the plant spreads to villages in the surrounding areas and is considered to have contributed to the increase in health complaints, most commonly respiratory, especially in winter. The Government and EGAT responded to this problem by introducing a scheme for the phased installation of the Flue Gas Desulphurization system (FGD) at Mae Moh. Commencing in 1992, the installation of the FGD system at power generation units 4–13 was completed in 2000 [2]. SO_2 emission has now been reduced to what is considered to be a satisfactory level.

To evaluate the efficacy of the FGD system, ecologically and economically, in terms of its contribution to protecting the environment, the LCA-*NETS* estimates the environmental impact of the power plant over its entire life cycle, and the LCC estimates the costs of the FGD system in terms of installation, operating and maintenance, and ongoing miscellaneous costs, at all stages in the operational life of the system. The objective of this study is to evaluate the LCA and LCC of the FGD system in terms of its impact on the environment. The lignite-fired power generation plant at Mae Moh has a capacity of 2,400 [mega watts] and can produce 14,167 [GWh] of electricity.

This study did not include the non-FGD installed electricity generating units 1–3 [3]. In this study, Life Cycle Assessment – Numerical eco-load total standardization (LCA-*NETS*) [5,6,7] system was used to evaluate the environmental impact by identifying and quantifying the energy and

materials used and the waste released into the environment, and also to identify and determine opportunities for the adoption of environmental improvement methods. The environmental impacts both in global and regional environmental issues were estimated into the Eco-values in new unit as [NETS]. This methodology is based on the balancing of the L & R (Loader and Receiver) theory. The second part of the study was the calculation of the LCC. And finally to propose ways to improve the power plant to gain further ecological and economical benefits.

1 Background

1.1 Proven reserves of coal in Thailand

In 2002, the proven reserves of coal in Thailand amounted to 1,332 [million ton]. 97% of the coal reserves are in the Mae Moh district, and almost all of that is low quality lignite. The discovery of new reserves of coal has increased the total proven reserve to 2,126 [million tons]. With coal consumption currently at about 18 [million tons per year], this would mean that Thailand has enough for the next 118 years. However, it has been determined that almost all of the coal reserves in Thailand are comprised of lignite with a high sulphur content and a low calorific value. These factors would contribute significantly to environmental damage and greatly reduce the combustion efficiency of coal-fired power plants. **Table 1** shows the characteristics of lignite found at the Mae Moh site [3,4].

Table 1: Coal analysis at Mae Moh mining area

Proximate analysis (as-received wt %)		Ultimate analysis, (dry basis)	
Fixed carbon	16.50%	C	39.23%
Volatile matter	28.50%	H	4.24%
Sulphur	2.41%	N	1.75%
Moisture	30.20%	S	3.17%
Ash	25.40%	O	22.33%
		Ash	29.28%
Heating value [kJ/kg-coal]		11,130–11,550	

Table 1 shows that lignite from the Mae Moh region is composed of a high amount of moisture and ash. These elements would contribute to the environmental impact and cause combustion problems. By contrast, Indonesian coal has a sulphur content of 0.3% and a calorific value of 22 [MJ/kg], and Japanese coal has a sulphur content of less than 1% and a calorific value of 26 [MJ/kg] [2,3]. In 2002, 16% of Thailand's electricity was produced from coal. As a result of the large proven reserves of coal, Thailand's Government is planning to stimulate an increase in its use for electricity generation in the future.

1.2 Overview of the Mae Moh lignite-fired power generation plant

The Mae Moh lignite-fired power plant has 13 power generating units. Units 1–3 are not in use as their life span is virtually at an end. Units 4–13 are the major producing units in the plant and all of these now have the FGD system installed and operating. **Table 2** shows each power generating unit's capacity, the amount of fuel it consumes and its electricity output.

Table 2: The characteristics of lignite-fired power plant

Power generating unit	Capacity [MW]	Fossil fuel consumption [TJ]	Generated electricity [TWh]
1-3 (3x75 MW)	225 (8.75%)	1.28 (0.86%)	0.092 (0.59%)
4-7 (4x150 MW)	600 (22.86%)	35.95 (24.07%)	3.55 (22.84%)
8-13 (6x300 MW)	1,800 (68.57%)	112.14 (75.08%)	11.90 (76.57%)
Total	2,625 (100.00%)	149.37 (100.00%)	15.54 (100.00%)

From Table 2, the power generation systems at units 4–13 were the major units at the electricity power generation. The generation units 1–3 operated at very low level approximately about 0.59% due to none of FGD system is installed and these units are running into the end of their life span.

1.3 Flue Gas Desulphurization System (FGD)

The area around Mae Moh has a serious acidification problem because the emissions from the power plant do not rise high enough into the atmosphere for wider dispersion. Many local residents and their cattle have been reported to be suffering from respiratory irritation. Following the Government and EGAT's decision to install the FGD system, in 1992 installation started at power plant units 12–13, followed by units 8–11, and then the newest units 4–5 and 6–7. Installation at the plant was completed in 2000 [2]. The wet scrubbing type of FGD uses ground limestone reagent to react with SO_2 from the flue gas producing gypsum (Calcium sulfate dehydrate: $CaSO_4$) byproduct like the chemical equilibrium below.

$$SO_2 + CaCO_3 + 1/2O_2 + 2H_2O \rightarrow CaSO_4.2H_2O + CO_2 \quad (1)$$

The performance of the FGD system is shown in **Table 3**.

As shown in Table 3, the FGD system has the potential to reduce the SO_2 emission by between 90–97%. This would mean that the SO_2 emission would not exceed the limit set by the Pollution Control Standard Division of Thailand.

Table 3: The average performance of the FGD system in 2001

Description	Unit	Quantity
Limestone	[ton]	1,198,691.00
Electricity consumption	[MWh]	446,137.70
Mass SO_2 inlet	[ton]	680,877.67
Mass SO_2 outlet	[ton]	25,947.79
Gypsum	[ton]	1,918,597.97
FGD efficiency	[%]	90–97%

2 Methodology

2.1 Life Cycle Inventory (LCI)

The LCI of the study was carried out according to the framework and procedures of ISO 14040 and ISO 14041 [9,10]. **Fig. 1** is a process tree of the system. Data for each unit process were collected for the input/output parameters determined by the cut-of criteria in the scope definition.

There are two major areas for data collection; upstream processes and power generation processes. Required data on environmental loads occurring in the upstream processes include data from the extraction of raw materials, transport, and processing to usable fuels. This is because resource consumption as well as environmental emissions occurs in these upstream processes. Public database or literature information such as report of the environmental loads of extraction of raw energy materials was used to obtain data for extraction. Actual transport distance as well as mode of transport was used for transport. For processing of raw energy materials to fuels, database available in the Thailand context, i.e. environmental load of converting crude oil to heavy oil for power generation was used. **Table 4** lists data sources of each upstream process used in this study. Lignite production data, however, came from the actual site as mentioned above. The inventory analysis of the lignite-fired power generation plant and FGD was developed as much as possible from the available data provided by EGAT. For further study, the actual and updated data at the site should be applied.

Fig. 1 shows the evolution of the Mae Moh power plant from the opening of the mine to the construction of the power plant and the installation of the FGD system. Inputs are the materials and energy consumed at each stage. Outputs are the electricity produced and the impact on the environment.

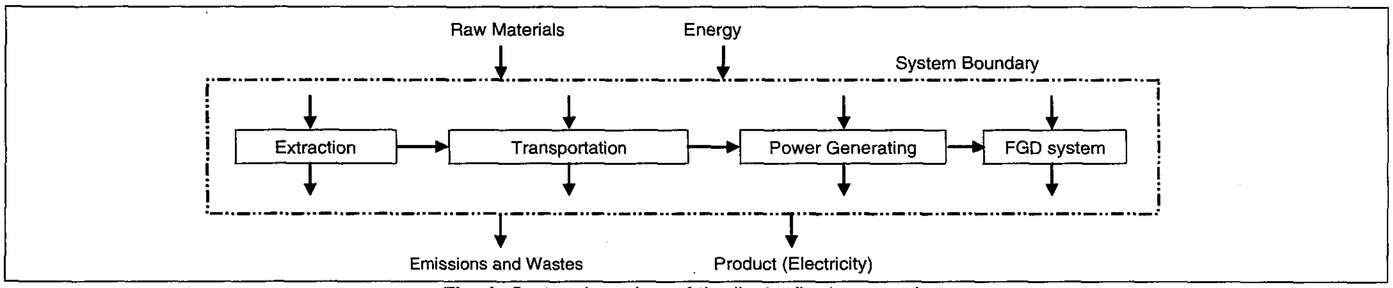

Fig. 1: System boundary of the lignite-fired power plant

Table 4: Environmental impact category handled by LCA-*NETS* and standard values for consolidation

Environmental impact category (*j*)	Related species (*i*) Number	Related species (*i*) Selected	Data source
Fossil fuels Depletion (FD)	4	Petroleum	Statistical White books, UN
		Natural Gas	
		Coal	
		Uranium	
Natural resources Depletion (ND)	42	Iron ore	UN, USGS
		Copper ore	
		Bauxite	
		Zinc ore	
Global Warming (GW)	6	CO_2	IPCC report, White papers on environment
		CH_4	
		N_2O	
		SF6	
Ozone layer Depletion (OD)	6	CFC-11	Environmental statistics, Documents in the industry
		CFC-12	
		CFC-113	
		HCFC-22	
Water Pollution (WP)	24	Pb	Environmental agency, National astronomical observatory, WHO
		As	
		Cr	
		Hg	
Air Pollution (AP)	6	CO	Environmental agency, National astronomical observatory, WHO
		C_6H_6	
		$ClCH{=}CCl_2$	
		$CCl_2{=}CCl_2$	
Rain Acidification (RA)	4	NO_2	Environmental agency, National astronomical observatory
		NO_2	
		N_2O	
		SO_2	
Waste Processing (WP)	2	Industrial waste	Environmental agency, Documents in the industry, White papers
		General waste	
Recycling Effect (RE)	43	Iron ore	Documents in industry, USGS

2.2 Life Cycle Impact Assessment (LCIA)

LCIA has been developed by the Energy System Design Laboratory, which aims to consolidate and quantitatively evaluate various environmental loads with different causes using the same standard [5,6,7]. This new method is called 'LCA-*NETS*' (Numerical Eco-load Total Standardization) which is the distance to target approach. The standardization could be conducted from various statistical data and regulation values published by public organizations such as the United Nations, the Government of Thailand et al. We often observed examples of standardization using subjective factors such as weight coefficients. Table 4 indicated type of environmental loads that LCA-*NETS* could handle at this moment and the basis of consolidated standard values.

LCA-*NETS* system sets a standard based on the Loader and Receiver Tolerance Balance Theory (L-R). The Loader here is the source of pollution i.e. power plants that emit CO_2 as a byproduct of combustion. The Receiver is the people in the local community and the ecosystem. The analysis of the environmental load was calculated through the balance between the maximum values that the Loader could emit (CO_2, NO_x and SO_x) or consumed (fossil fuel or natural resources) and the maximum tolerated values of the Receiver. This approach has the additional feature of allowing a complete quantitative evaluation of the various environmental loads in the new LCIA's unit as [NETS].

L-R Balance Theory defined, first of all, the Maximum Permissible Eco-load Value (MEV_i)[NETS] for a given environmental load (i), which is tolerated to Receiver. For example, MEV_i for global environmental impact (G) that the world population is able to tolerate is defined as follows:

$$MEV_i^G = 6.0\times10^{11}[NETS] \tag{2}$$

The superscripted 'G' in equation (2) indicated the global scale environmental load, and the subscripted 'I' was the environmental load factor class 'i'. Here, the total population of the world in year 1999 was equal to 6.0 x 10^9 [persons], assuming that the basic tolerable value for a man was equal to 100 [NETS]. The tolerable value for a person was determined as 100 [NETS] due to the tolerance level has set to be 100% for being the standard of living that people could enjoy. For example, people in countryside are satisfied when they can breathe the fresh air without pollution. By contrast, urban dwellers have to breathe air containing high level of gas emissions, therefore it could be said that country folk have a higher quality of life than urbanites. The quality of life can be measured using NETS impact values, the less environment impact value, the better people can be satisfied their living.

The maximum tolerance value is presented by P_i [ton, kWh, m^3, etc.] value and according to the L-R Tolerance Balance Theory; we could get the equation as shown below.

$$P_i \times ELM_i = MEV_i \tag{3}$$

Here, ELM_i [NETS/ton, kWh, m^3, etc.] (Environmental Load Module) was the conversion coefficient connecting with P_i [ton, kWh, m^3, etc.] and MEV_i [NETS]. ELM_i can also refer to the consolidated environmental impact for unit emission or unit consumption.

As the LCA had to be summarized along all stages of the life cycle, the total LCs environmental load consolidated value *EcL* [NETS] was calculated using the following formula.

$$EcL = \sum_{i=1}^{n}(ELM_i \times x_i) \tag{4}$$

Here, x_i [tons, kWh, m^3, etc.] is the emission amount or the consumed amount of the related environmental load factor class 'I'. The following procedure is shown for acquiring the maximum emission/consumption amount P_i and the environmental load consolidated standard ELM_i, taking factors such as depletion of fossil fuel, global warming by CO_2 and other greenhouse gas emissions, atmospheric pollution (CO, Benzene, $CHClCCl_2$ and C_2Cl_2) and acid rain, to which power plants were directly contributed [6].

2.3 The calculation model of *NETS* (i.e. global warming)

The Inter-Governmental Panel on Climate Change (IPCC) reported on climatic variations that, if the best scenario S450 for CO_2 concentration in the atmosphere is followed, the CO_2 concentration can be stabilized at 450 [ppmv] by 2100. Otherwise, unless action has been taken, our present way of life cannot be maintained. Needless to say, the environmental load from global warming is on a global scale [5,6,7].

The accumulated emission of CO_2 concentration which is necessary to stabilize the concentration at 450 [ppmv] was defined as the maximum allowable emission P_i in the Loader side. The maximum allowable emission amount of CO_2 from 1900 to 2100 was estimated as 2.31 x 10^{12}, after calculating the mass of air in the atmosphere (troposphere up to an altitude 50 km) as 5.45 x 10^{18}, and the amount of 0.24 x 10^{12} emitted between 1991 and 1999, the maximum allowable emission amount , and the consolidated environmental load standard value ELM_{CO2}^{GW} could be calculated respectively as follows.

$$P_{CO2}^{GW} = 2.07\times10^{12}[\text{ton}], ELM_{CO2}^{GW} = 2.9\times10^{-1}[\text{NETS/ton}] \tag{5}$$

To calculate the consolidated environmental load for global warming from greenhouse gases other than CO_2, equation (5) multiplied by GWP (Global Warming Potential) for CO_2, namely $EML_i^{GW} = GWP_i \cdot ELM_{CO2}^{GW}$ was used. **Table 5** showed the values of six types of greenhouse gases. CO_2 gas absorption by the oceans, as highly reliable data was not available at present; therefore it has not been considered.

Table 5: GWP and ELM (1999) for global warming from greenhouse gases

Greenhouse gas	GWP [–]	ELM_i^{GW} [NETS/kg]
CO_2	1.0	2.9×10^{-4}
CH_4	24.5	7.1×10^{-4}
N_2O	320	9.3×10^{-2}
R-11	4,000	1.2×10^{3}
R-22	1,700	4.9×10^{-1}
SF_6	24,900	7.2×10^{0}

2.4 LCIA evaluation model

In order to compare the environmental advantages and disadvantages of the FGD system installed at power plants, LCA-*NETS* calculation models (6,7,8) were developed as decision-making tools when selecting pollution control equipment for a power plant [14,15].

$$\sum EcL_{PP\ without\ FGD} = \frac{EcL_{PP}^{In} + 30 years \times EcL_{PP}^{Op}}{\sum E_g} \tag{6}$$

$$\sum EcL_{FGD} = \frac{EcL_{FGD}^{In} + 30 years \times EcL_{FGD}^{Op}}{\sum E_g} \tag{7}$$

$$\sum EcL_{PP\ with\ FGD} = \frac{(EcL_{PP}^{In} + EcL_{FGD}^{In}) + 30 years \times (EcL_{PP}^{Op} + EcL_{FGD}^{Op} - E_{re})}{\sum E_g} \tag{8}$$

where

$EcL_{PP\ with\ FGD}$ = Eco-load of power plant with FGD installation [NETS/kWh]

$EcL_{PP\ without\ FGD}$ = Eco-load of power plant without FGD installation [NETS/kWh]

$EcL_{PP}{}^{In}$ = Initial eco-load of power plant

$EcL_{FGD}{}^{In}$ = Initial eco-load of FGD

$EcL_{PP}{}^{Op}$ = Operating eco load of power plant

$EcL_{FGD}{}^{Op}$ = Operating eco-load of FGD

E_{re} = Environmental reduction after installed FGD

ΣE_g = Total electricity generation in life cycle

The subscript '*In*' indicated the state of power generation plant and the FGD system at the construction stage. The subscript '*Op*' is meant operation and maintenance of power generation plant and the FGD system at the operation stage.

Formulas 6 and 7 are used to calculate the life cycle environmental impact of the power plant before the installation of the FGD system. The initial stage is included the mining and construction stages and to operation stage is also included the maintenance stage. Formula 7 is used to calculate the life cycle environmental impact of the power plant after the installation of the FGD system.

2.5 LCC evaluation model

LCC was used to calculate the total cost of the FGD system during its entire life cycle – from the mining of limestone, its transportation, operation of the system, to disposal of waste, per unit of electricity generated. The following equation (9) is the life cycle costing model for determining the total life cycle cost of the FGD system where all costs or benefits were expressed as net present values at the base point [16].

Table 6: Economical cost of the FGD system at lignite-fired power plant

Parameter	Value
Unit lifetime	Up to 30 [year]
Investment cost (8 units)	170.00 x 10^6 [$US]
Maintenance cost	2.90 x 10^6 [$US/year]
Operating cost	19.46 x 10^6 [$US/year]
Limestone cost	1.99 x 10^6 [$US/year]
Others cost	15.54 x 10^6 [$US/year]
Interest rate	8%
Rate of growth	5%

$$LCC_{FGD} = \frac{\sum_{j=1}^{8} NPV_j^{FGD}}{SO_2} \tag{9}$$

where:

LCC_{FGD} = Life cycle costing of FGD at unit '*j*' [$US/ton. SO_2, yen/ ton.SO_2, baht/ ton.SO_2, etc.]

NPV_j^{FGD} = Net present value of FGD at unit '*j*' [$US, yen, baht, etc.]

SO_2 = The amount of SO_2-equivalent emission

Table 6 shows the economic information for the FGD system installed at the Mae Moh power plant. The life span of the FGD system is assumed as 30 [years], equal to life span of the power plant generating units. The LCC cash flow started at year 0 with the investment cost at each unit. The total investment cost of 8 FGD units equal 170.00 × 10^6 [$US. dollars] while there were the annual costs, for instance, maintenance cost, operating cost, limestone cost and other costs.

According to the economical data, the total cost in life cycle was calculated into net present value as shown in equation 10. The net present value was able to indicate the cost and benefit of the FGD system from the economical point of view.

$$NPV_j^{FGD} = \sum_{n=0}^{30} \frac{TC_n}{(1+i)^n} \tag{10}$$

where:

NPV_j^{FGD} = Net present value of FGD at unit '*j*' [euro, yen, baht, etc.]

TC_n = Total cost at year '*n*' (i.e. investment cost, annual cost, savage cost and other costs) [euro, yen, baht, etc.]

'*i*' = interest rate [%]

'*n*' = Life span of FGD (Hence, life span of FGD = 30 years)

3 Results and Discussion

In order to analyze and estimate the total environmental impact of the lignite-fired power plant before and after the installation of the FGD system, the LCA-*NETS* system evaluated the five main categories of environmental impact.

3.1 EcL of the lignite-fired power plant before installation of the FGD system

The LCA for total environmental impact is analyzed in **Fig. 2**.

Fig. 2 shows that most environmental damage occurs at the direct fuel consumption stage in the process. The direct fuel consumption stage is when the power plant is consuming fossil fuel (lignite and diesel) for electricity generation. Power plants consume fossil fuel during their entire life span, assumed to be 30 [years]. Because fossil fuel is a non-renewable energy resource, the potential damage to the environment is high.

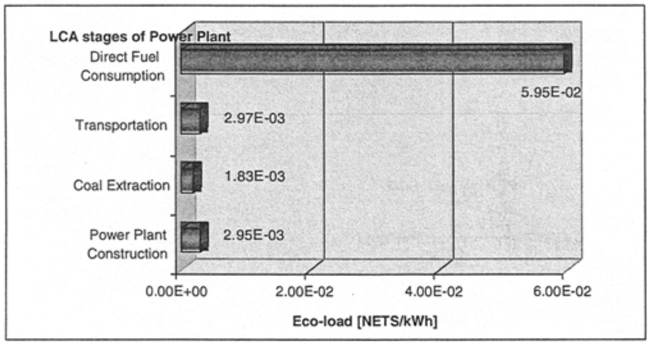

Fig. 2: Eco-load of power plant before the installation of the FGD system in each LCA stage

The transportation, construction and coal extraction stages have a lower level of impact on the environment. Details of the environmental impact categories are illustrated in **Fig. 3**.

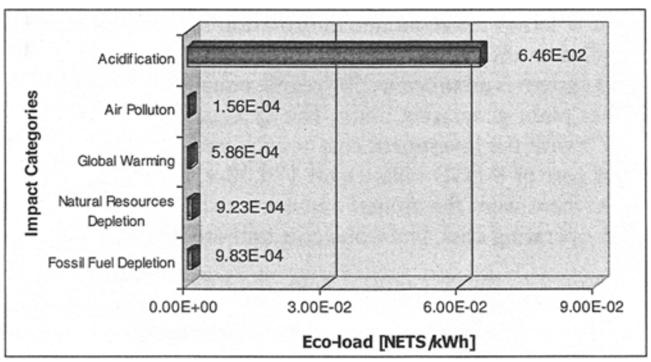

Fig. 3: Eco-load of power plant before the installation of the FGD system in each impact category

As shown in Fig. 3, the greatest damage to the environment is caused by acidification. The acidification problem occurs at the direct fuel consumption stage as a direct result of the low quality of the lignite. This graph clearly shows that the installation of the FGD system can significantly reduce the impact of acidification on the environment. Although Thailand has abundant reserves of lignite, the environmental impact resulting from the depletion of fossil fuels cannot be ignored.

3.2 EcL of the FGD system

The FGD system will reduce the impact of acidification; however, the operation process of the system itself has an impact on the environment. The LCA-*NETS* model of the FGD system evaluates the impact (**Fig. 4**).

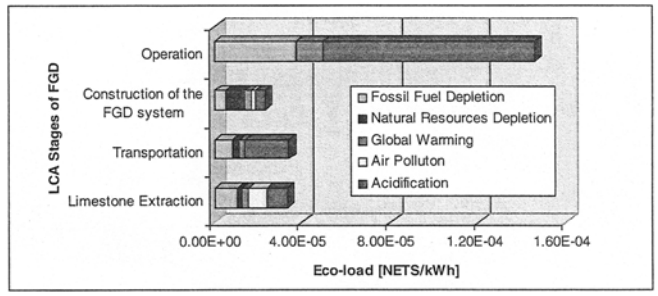

Fig. 4: Total environmental load of the FGD system

Fig. 4 clearly shows that the operational stage of the FGD system has a higher ongoing environmental impact than any of the other stages. The main environmental problems are the acidification, fossil fuel depletion and global warming, respectively. Although, the FGD system is able to reduce SO_2 emission from the combustion of the power plant but the FGD system consumed also the electricity for operating. Therefore, the electricity that is consumed by the FGD system contributed to the acidification problem as well.

3.3 Comparison of the environmental impact of the power plant before and after installation of the FGD system

After the installation of the FGD system, the SO_2 emission was reduced to a level below the regulation standard. **Fig. 5** shows the comparison of SO_2 emission levels before and after installation of the FGD system.

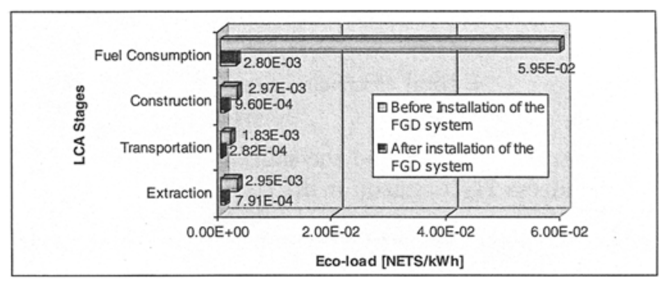

Fig. 5: Eco-load value of the power plant before and after the installation of the FGD system

Fig. 5 shows that the greatest reduction of environmental impact, 95%, was achieved at the direct fuel consumption stage in the power plant process. The comparison of eco-load values is shown in **Table 7**.

Table 7 clearly shows that the installation of the FGD system reduces the power plants negative impact on the environment, in terms of sulphur emission, by 93%.

Table 7: Eco-load of power plant before and after the installation of the FGD system

Impact categories of power plant	After installed FGD [NETS/kWh]	Before installed FGD [NETS/kWh]	Percentage [%]
Fossil fuel depletion	9.97E-04	9.83E-04	(1.52)
Natural resources depletion	9.23E-04	9.23E-04	0.07
Global warming	5.54E-04	5.86E-04	5.57
Air pollution	1.62E-04	1.56E-04	(4.19)
Acidification	2.20E-03	6.46E-02	96.59
Total	**4.83E-03**	**6.72E-02**	**92.81**

3.4 Life cycle costing calculation results of the FGD system

The LCC system was used to understand the economic aspects of the FGD system. The power generation plant is a based-load power plant, therefore, the generating rate is assumed at 70% of full capacity. The serviceable life of a power plant is assumed to be 30 years. **Fig. 6** shows the main costs of the FGD system: investment, operation and maintenance, limestone, and other miscellaneous costs. It will be seen from Fig. 6 that the highest cost associated with the FGD system is the investment cost, a direct result of the importation of the system from Japan and Italy.

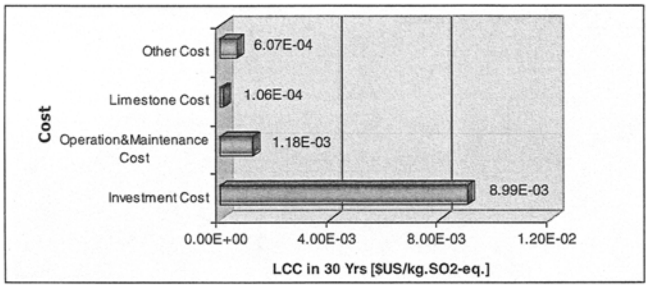

Fig. 6: Life Cycle Costing of the FGD system [$US/kgSO$_2$-equivalent]

3.5 The SO_2 taxation incentive

The SO_2 tax was introduced in 1999 on the recommendation of a national green tax commission. The Norwegian government announced in 2001 that the tax on SO_2 emissions would be scrapped in favor of voluntary agreements with business. The environment ministry will propose the current levy of 0.38 [EUR/kg-SO_2] or 0.43 [$US/kg-$SO_2$] on emissions from coal and coke-burning and oil refineries would be terminated. Instead, industries will be invited to participate in a voluntary program to reduce sulfur emissions as required under the Gothenberg protocol [17].

In relation to the SO_2 tax, **Table 8** shows the economical benefits that may be derived from the installation of the FGD system.

Table 8 shows that, over the entire life time of the power plant, the installation of the FGD system can reduce the payment of SO_2 tax by approximately 7,258 [million. US$], or 88%.

Table 8: Comparison of LCC of the FGD system and SO_2 tax

Comparative directions	Cost for SO_2 control		
	$US/kgSO$_2$	$US/kWh	Million. $US (in 30 years)
LCC of FGD	0.05	2.33E-03	1,028
SO_2 Tax	0.43	1.88E-02	8,286

4 Conclusion

The results of this study demonstrate conclusively that the negative impact that lignite-fired power generating plants have on the environment can be significantly reduced by the installation of the FGD system. The benefits, both ecological and economic, to be derived from the use of the FGD system far outweigh the systems inherent negative environmental impact. Given the adverse characteristics of the lignite in Thailand: high sulphur content and low calorific value, it is essential that all lignite-fired power plants should have the FGD system installed to ensure the continuing sustainable development of the power generation industry in Thailand. As an incentive to electricity producers, the Polluter Pays Principle (PPP), the environmental tax system, should be introduced in Thailand to encourage producers to rapidly improve their environmental policies. Furthermore, the development of more effective SO_2 control equipment and new technology for coal-fired power plants should be emphasized in order to minimize environmental impact and maximize the efficient consumption of non-renewable fossil fuels.

5 Outlook

The development of LCC/LCA analysis models allows EGAT and other Independent Power Producers to judge the comparative values, both in ecological and economic terms, of new technology designed to reduce environmental impact. In particular, LCA-*NETS* is a valuable tool when assessing the environmental impact of any type of power plant, and to indicate future trends of potentially harmful environmental degradation. Reducing the environmental impact and the cost of producing power are essential for the sustainable growth of power generation facilities necessary to meet Thailand's ever increasing demand.

Acknowledgement. The authors would like to express their gratitude and appreciation to the Hitachi Scholarship Foundation without whose generous financial support this study would not have been possible. Thank you.

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Recieved: June 16th, 2004
Accepted: September 27th, 2004
OnlineFirst: September 28th, 2004